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Technical Memorandum

A REVIEW OF TRISTEN EXPERIMENTAL RESULTS

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A REVIEW OF TRISTEN EXPERIMENTAL RESULTS

An invited paper presented at the Arctic special session of the 12th ICA, Toronto July 25, 1986.

Abstract

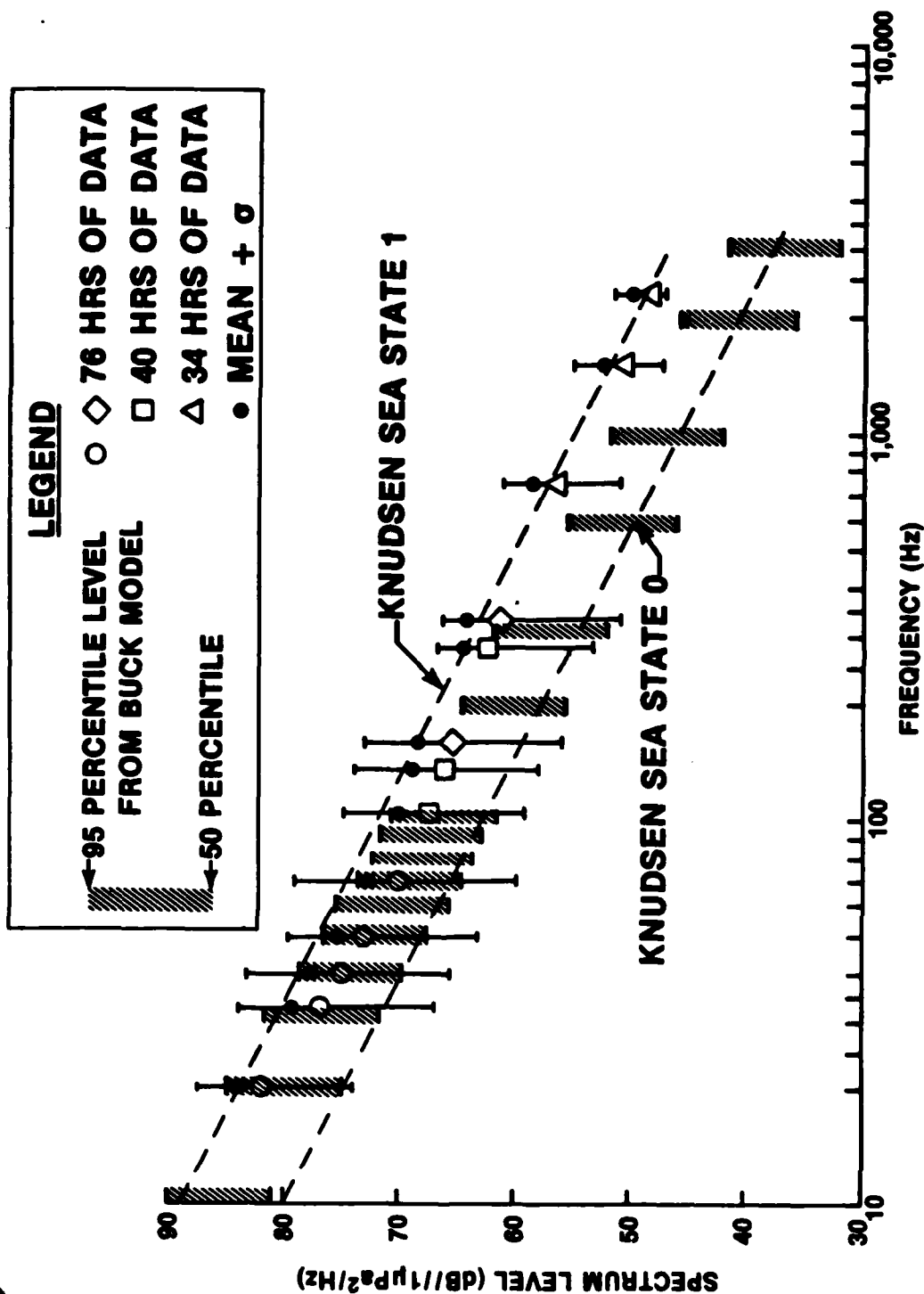
TRISTEN experiments have been conducted in each of the three different Arctic environments; (a) Pack Ice, (b) Marginal Ice Zone (MIZ) surrounding the Pack Ice, and (c) the open water between the MIZ and the Arctic circle. The major findings from these experiments, started in 1980, are summarized below.

Introduction

TRISTEN experiments have been conducted (in association with the ONR Arctic Program) during 1980, '82 and '84 in each of the three distinctly different Arctic Environments, namely: (a) The Pack Ice located over the deep water central Arctic Basin, (b) The Marginal Ice Zone (MIZ) located on the periphery of the Pack Ice in predominantly shallow water, and (c) Arctic Open Water Regions which lie between the MIZ and the Arctic Circle and which also have large areas of shallow water. TRISTEN experimental results for propagation loss, ambient noise and medium stability, shall be summarized for each of these three regions individually and where possible amongst the three environments. Of the three environments, acoustic characterization is easiest within the Pack Ice. So we shall begin with it.

*20 pages of handwritten notes
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FRAM IV/TRISTEN-82 (PACK ICE)



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Figure 1

Figure 1

The open circles, diamonds and rectangles represent ambient mean noise levels obtained at FRAM IV in 1982 by averaging data over the month of April. The solid circles represent the mean plus one standard deviation. In addition we have also plotted the highest and lowest average values measured which are shown by the bars. It is seen that the mean values fall between the Knudsen Sea State 0 and 1 curves indicating that Pack Ice noise is in general lower than average noise from more temperate oceans. At frequencies below 100Hz the minimum values are lower than the sea state 0 curves so that at times noise in the Pack Ice can be exceptionally low. The shaded bars are predictions from an empirical model due to Buck for the month of April (which was the month of the TRISTEN data) for 50 through 95 percentile noise levels. The agreement between Buck's empirical predictions and our measurements is quite good. This coupled with the fact that Buck's data base spans all 12 months and many different central Arctic locations gives us confidence that mean level ambient noise prediction in the central Arctic is well in hand.

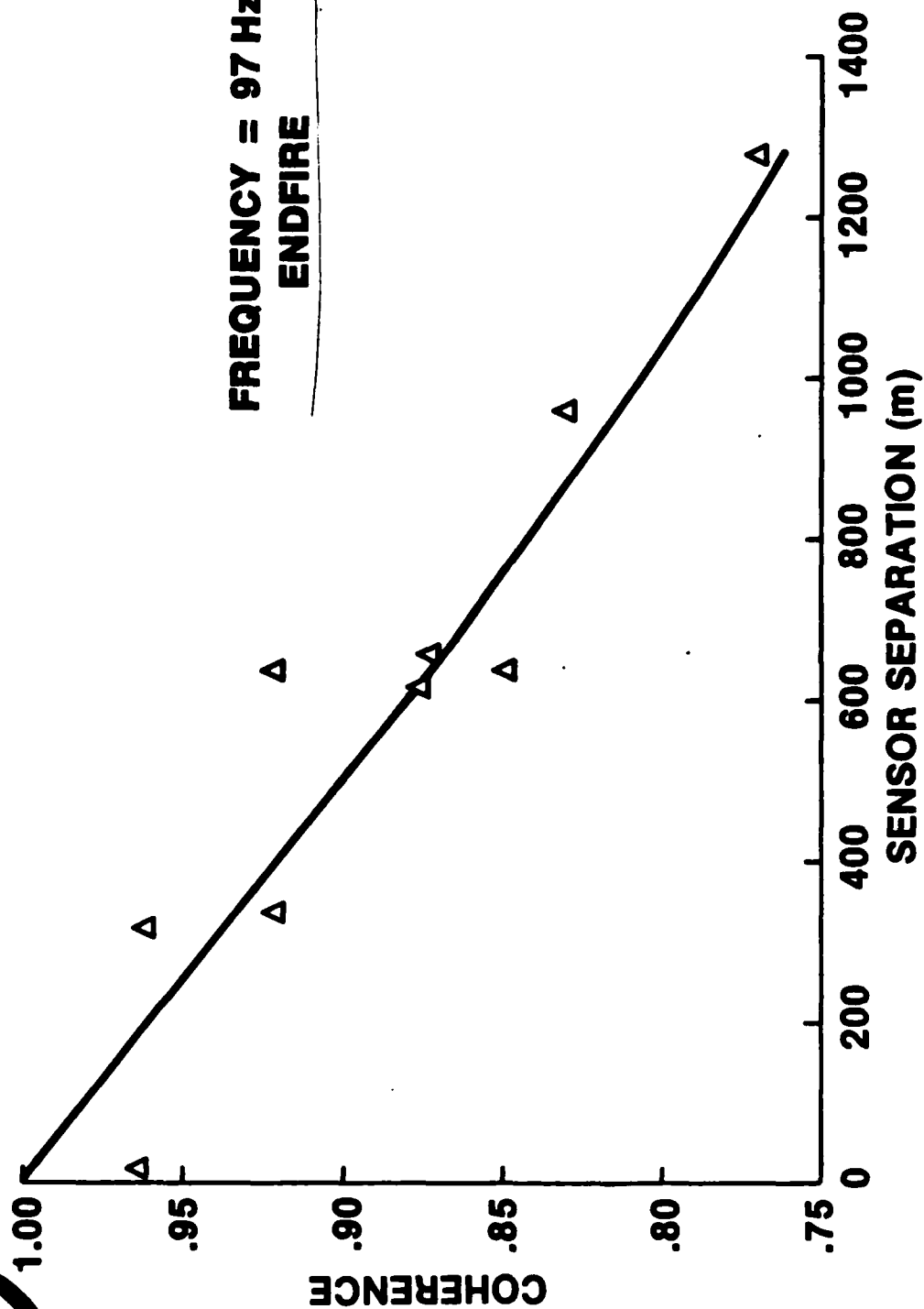


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COHERENCE VS SENSOR SEPARATION

FREQUENCY = 97 Hz
ENDFIRE



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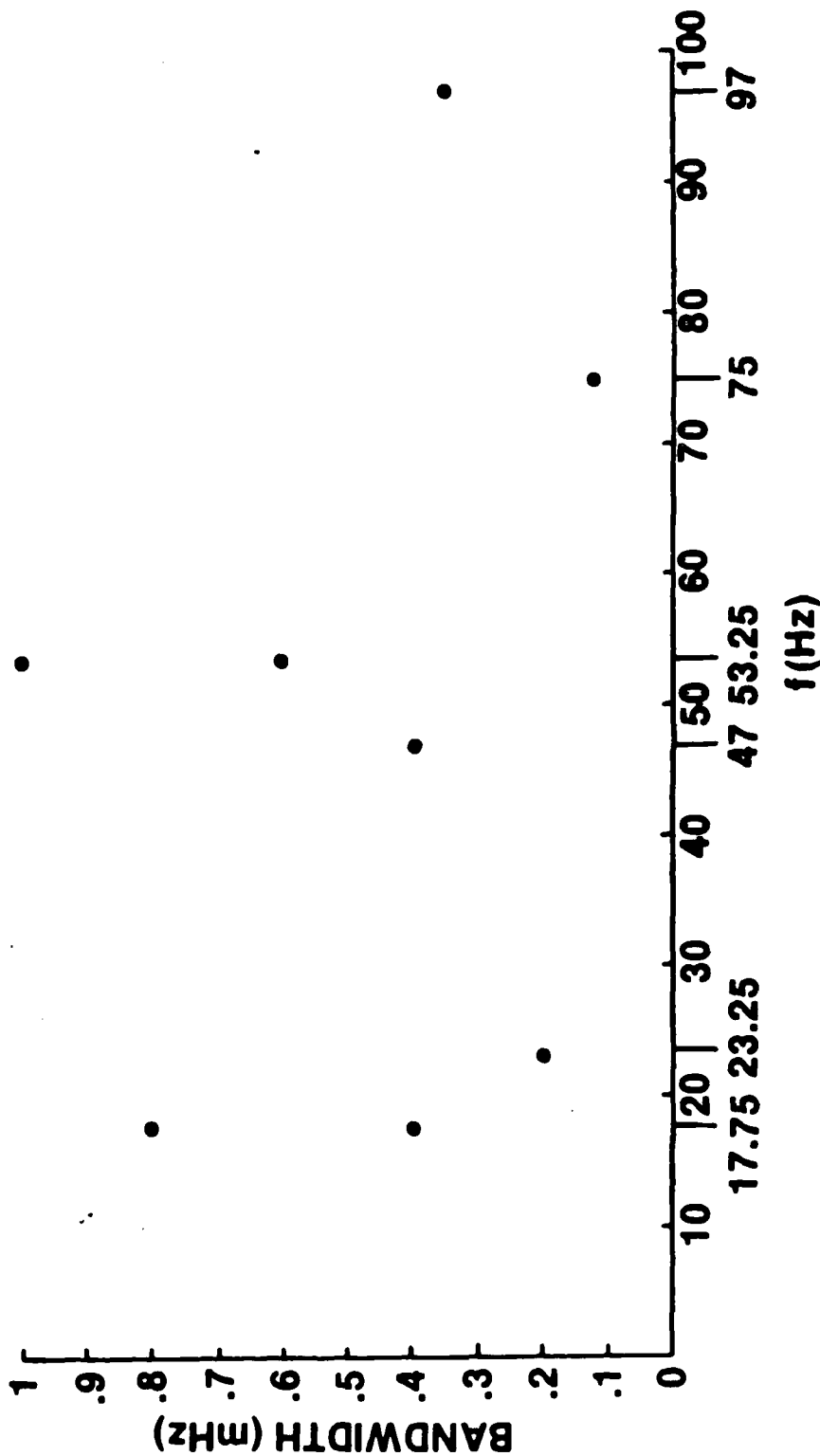
Figure 2

Spatial coherence calculations were made from a fixed source to the MIT/WHOI fixed receiver at FRAM IV for frequencies up to 97Hz. Shown is the result at 97Hz for which we experienced the largest degradation. Note however, that even in this case the coherence never gets below .75 for an aperture length of 1.3km. Since in this case both source and receiver are stationary the high coherence implies high medium stability.



TRISTEN-82 FIXED SOURCE/FIXED RECEIVER 3 dB DOWN BANDWIDTH FOR CW TONES

$\Delta f = \begin{cases} .12 \text{ mHz} & \text{WITH ZEROS} \\ .27 \text{ mHz} & \text{WITHOUT ZEROS} \end{cases}$ • SIGNIFICANT FREQUENCY SPREADING < 1 mHz



L3775q

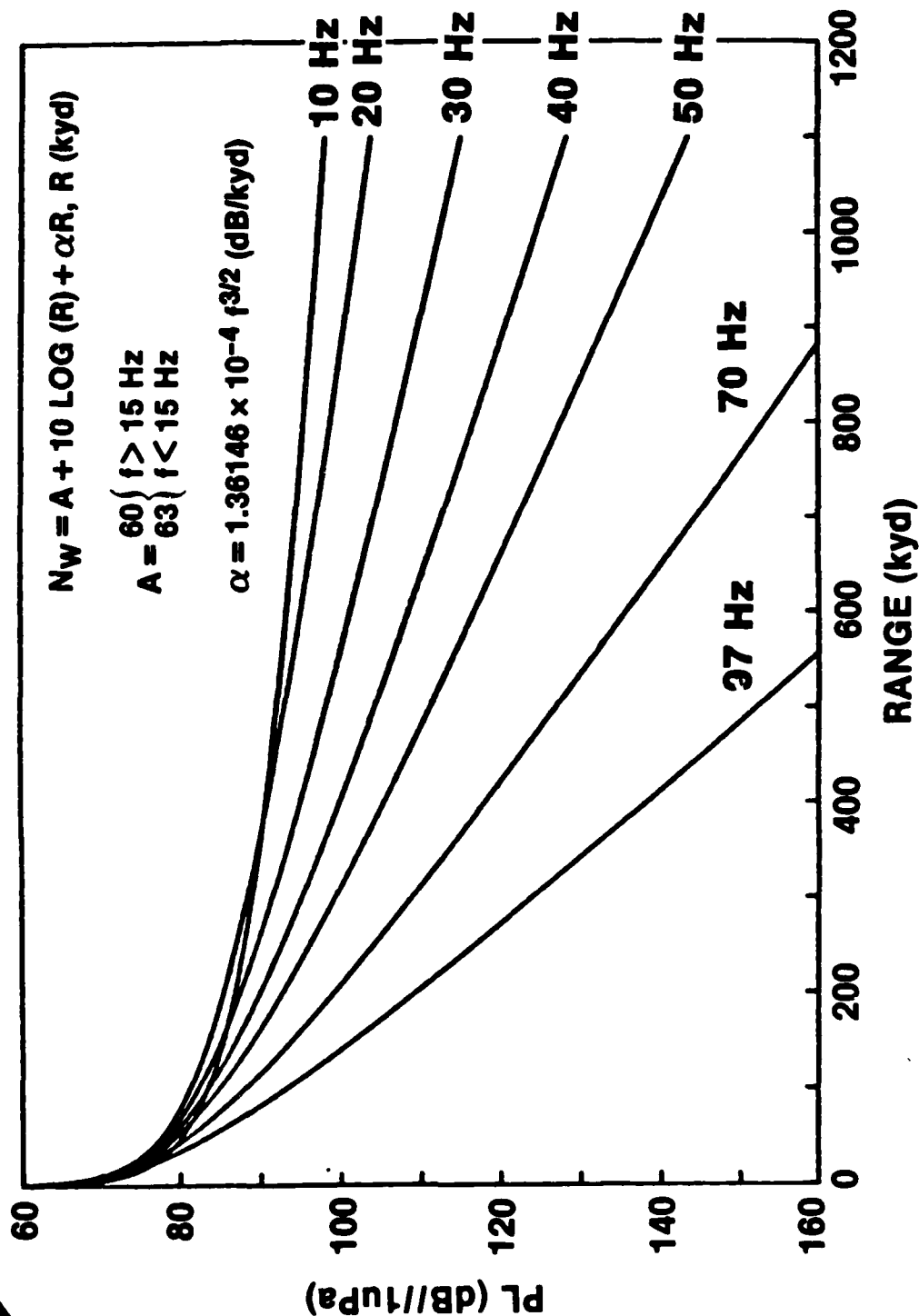
Figure 3

Figure 3

Another indicator of medium stability is the bandwidth over which energy is spread from a long duration tone transmitted from a fixed source to a fixed omni directional receiver. Such data was collected during the '82 experiment. A cumulative energy analysis was made on the spectrum of demodulated 1 hour CW transmission at frequencies from 18 to 97Hz. The bandwidth was measured at the 3db down point centered on the medium cumulative energy frequency. The result of these bandwidth calculations plotted in millihertz along the vertical shows that the maximum spreading for all frequencies less than 100Hz was less than 1 millihertz which leads us to believe that the Pack Ice may be the most stable environment for low frequency acoustics. This fact correlates well with measurements of internal waves, eddies and currents which for the Pack Ice have magnitudes considerably smaller than similar values for more temperate oceans. The explanation for this may lie with the unique solid ice canopy.



TRISTEN PACK ICE EMPIRICAL PROPAGATION LOSS EQUATIONS



L50542bP

Figure 4

Figure 4

The Pack Ice provides an almost text book example of acoustic propagation in a range independent environment at low acoustic frequencies if one could ignore the influence of scattering from the rough ice canopy. This can be seen by examining the empirically derived expression and curves shown. The first two terms of the empirical expression ($A + 10 \log(R)$) represent the classical result for a range independent environment. The last term, αR , is similar in form to attenuation loss from ice free temperate oceans, but in this case it is dominated by scattering loss and furthermore is two orders of magnitude larger. The scattering loss was found to be proportional to frequency to the three halves power which results in a significant increase in loss even at low frequencies at long ranges.

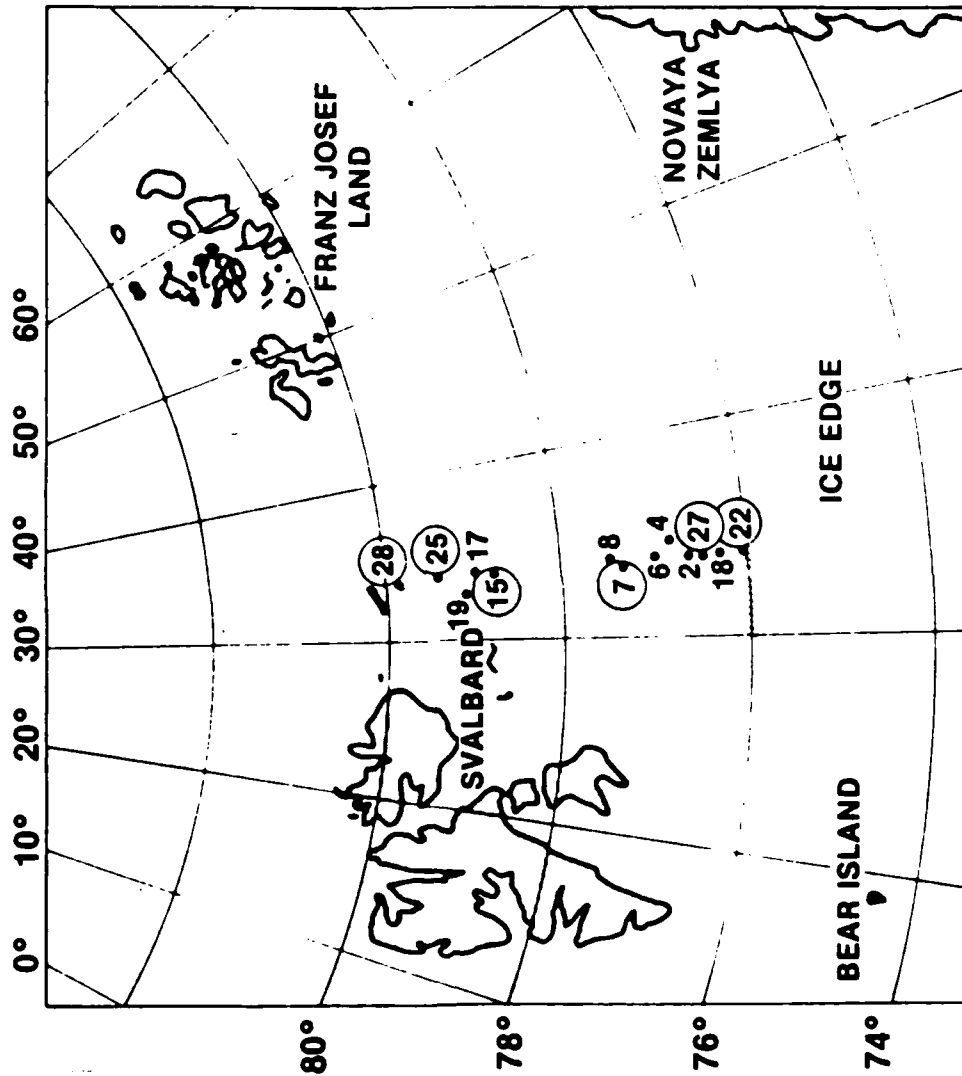
It is clear that the salient environmental factor for low frequency acoustics in the Pack Ice is the unique solid ice cover. It prohibits shipping from entering the region which probably accounts for the low mean ambient noise levels. The lower magnitudes of internal waves, eddies, and currents, which accounts for the exceptional acoustical stability, is also most likely a direct result of the ice cover; and it certainly dominates propagation through scattering and the range independence of the sound speed profile.

Since the ice cover is no longer solid in the MIZ and absent in the open water regions, one might expect that acoustic characterization is going to be considerably more difficult in these Arctic environments. We shall shortly provide evidence that this is indeed the case. However, the fact that the Pack Ice lies predominantly over deep water while the MIZ and open water region lie predominantly over shallow water also contributes to the complications of characterizing acoustics in these Arctic environments. Our discussion begins with ambient noise in the MIZ.



"TRISTEN-82"

BUOY LOCATIONS IN THE MARGINAL ICE ZONE (APRIL 1982)



L606291

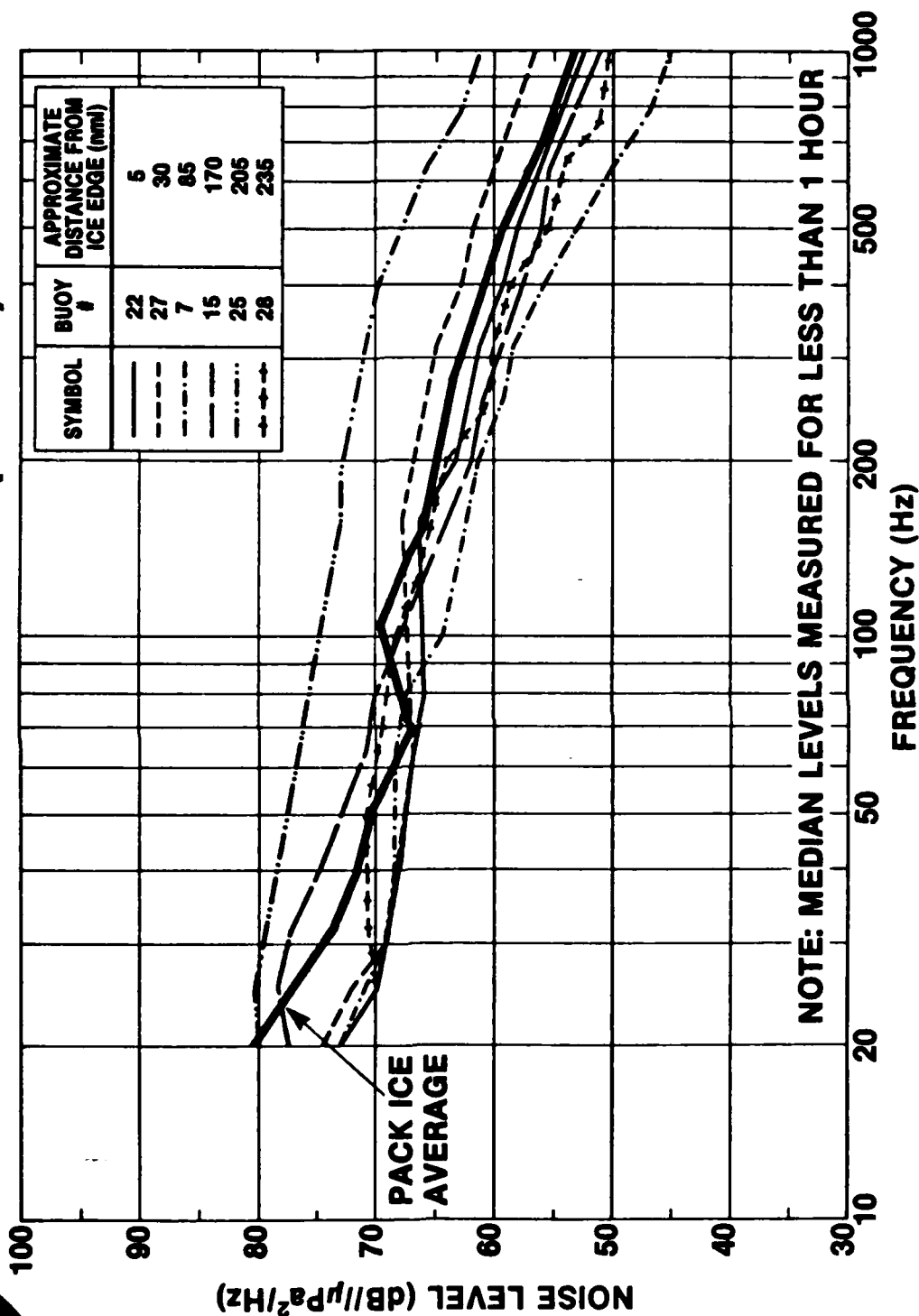
Figure 5

As part of the TRISTEN-82 experiment a number of sonobuoys were dropped in the shallow water Barents Sea MIZ from the ice-edge back towards the Pack Ice. Data from the buoys, which span a distance of about 200nm in a fairly uniform water depth of about 1000', were collected simultaneously. In order to provide an indication of the spatial variability of the mean ambient noise level it is sufficient to discuss the data from only those buoys which are circled.



"TRISTEN-82"

AMBIENT NOISE VARIABILITY IN THE MARGINAL ICE ZONE (APRIL)



L60629a

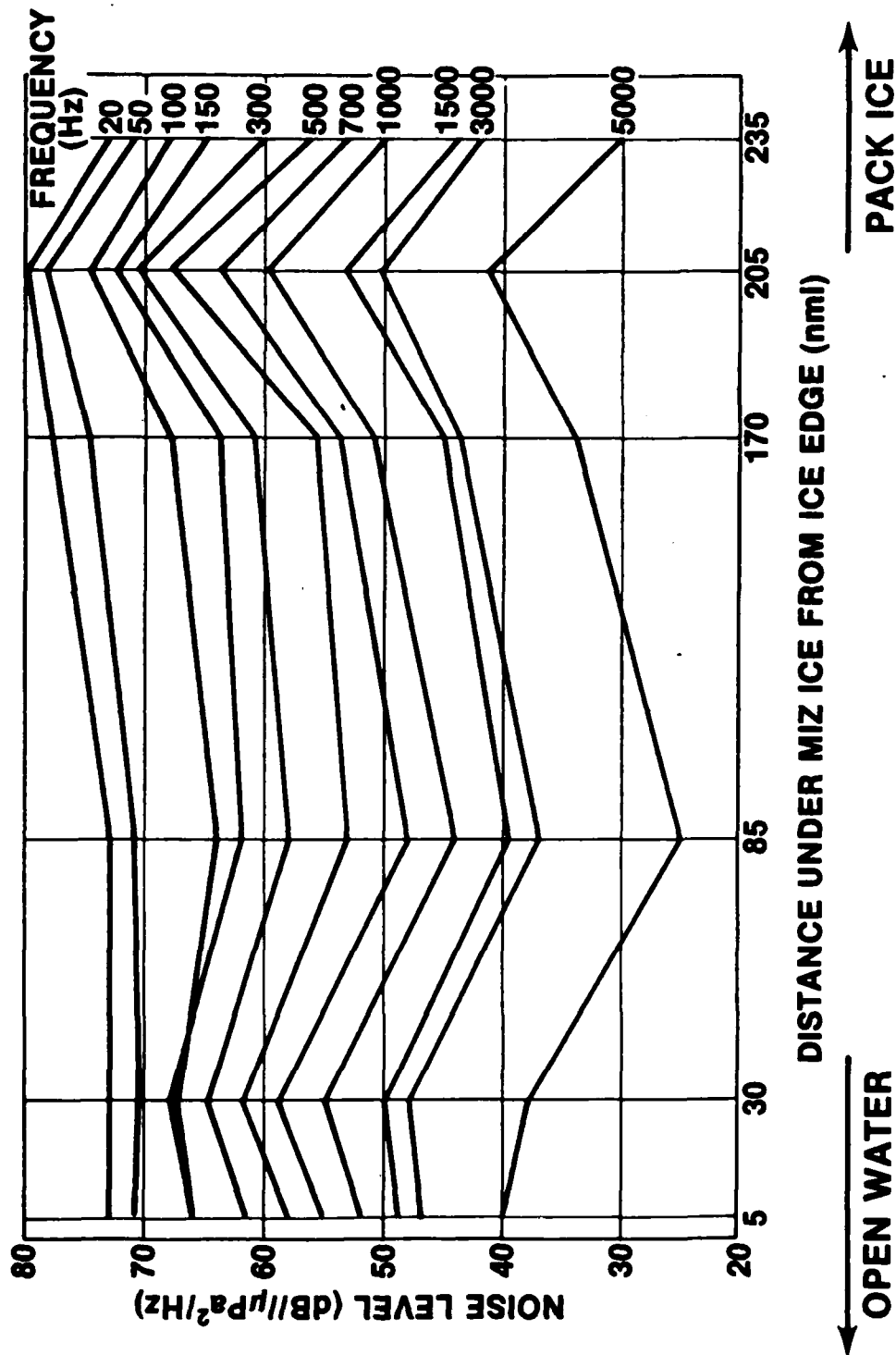
Figure 6

The average levels from the circled buoys are plotted versus frequency along with the average level from the Pack Ice shown previously. It is evident that the mean MIZ level can either be higher or lower than the Pack Ice result depending upon where in the MIZ the measurement was made. In this instance the lowest noise occurs on the buoy closest to the ice edge, and the levels on this buoy are lower than those found in the Pack Ice, while the highest noise occurs on a buoy 205nm from the ice edge. Considering that this data set only spans a 3 hr period we would not expect this to always be the case, but it is safe to say that MIZ noise is highly dependent upon location within the MIZ and it is possible to find noise levels that are both higher and lower than those found in the Pack Ice.



"TRISTEN-82"

AMBIENT NOISE IN THE MARGINAL ICE ZONE VS. DISTANCE FROM ICE EDGE (APRIL)



L60829c

Figure 7

To determine if a trend of level with distance under the MIZ exists we have plotted level on the vertical axis and distance under the MIZ on the horizontal axis with open water to the left and Pack Ice to the right. At each buoy distance along the horizontal axis the levels from that buoy at frequencies from 20 to 5000Hz are plotted and the points at the same frequency for all buoys are connected. Following the curve for any one frequency one might expect to see the highest level occurring closest to open water and then decreasing in value as we proceed to the right further under the MIZ towards the Pack Ice. This is not the case. In fact some of the highest levels measured were at a distance of 205nm from open water while some of the lowest levels occurred at the buoy closest to open water. The only trend evident, other than the fact that the level always decreases as frequency increases, is that levels at any one buoy tend to rise and fall simultaneously at all frequencies. For example at 85nm the levels are all dropping, at 205nm they all increase and just 30nm away at 235nm they all drop again. The lack of consistency of level with distance under the MIZ coupled with uniform rise and fall levels over closely spaced buoys leads us to believe that MIZ noise is governed by very local conditions of wind and current and that these environmental factors have a much smaller spatial correlation length than that for the deep water Pack Ice. We next discuss the medium stability of the MIZ based upon data taken in June as part of the TRISTEN/MIZEX-84 experiment.

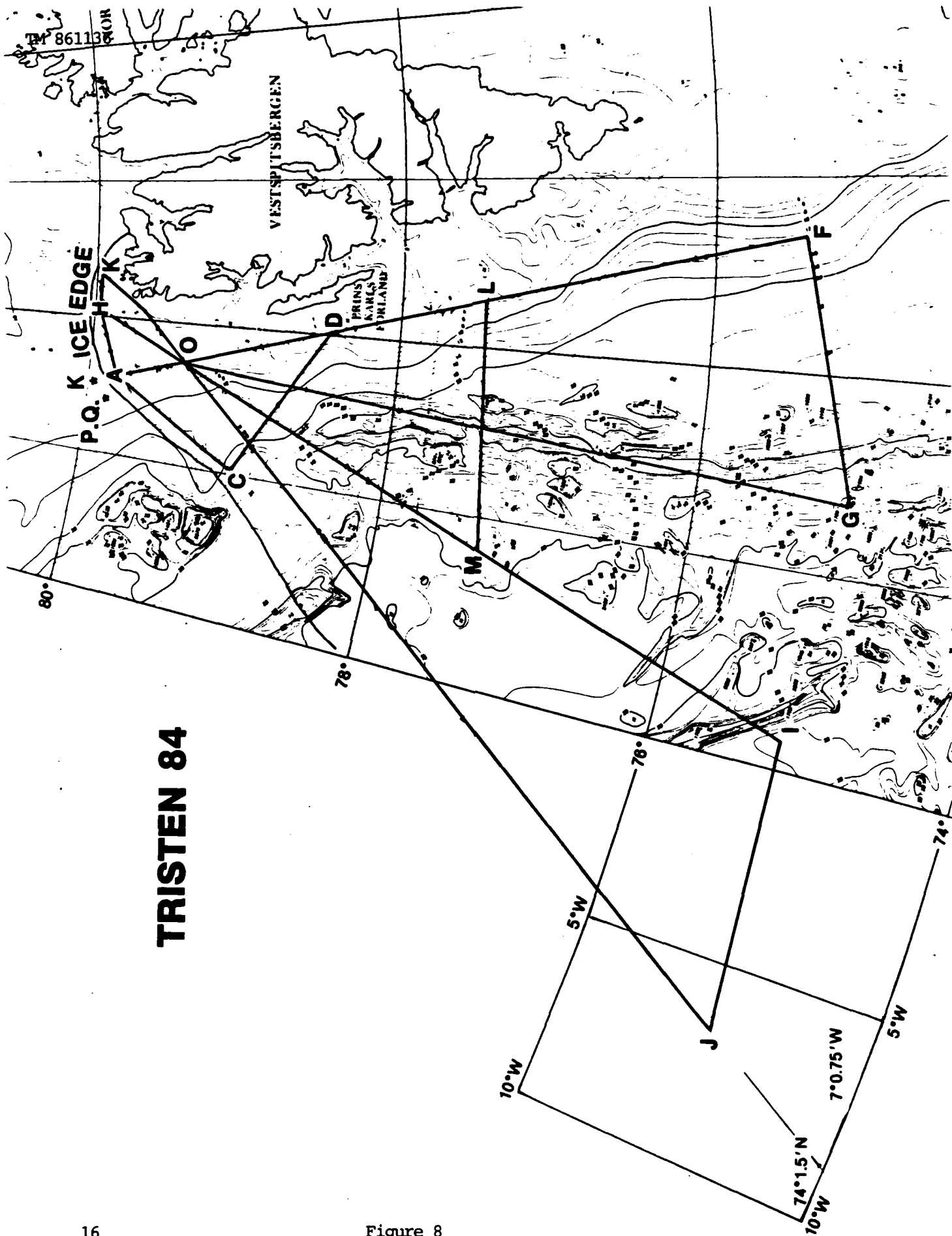
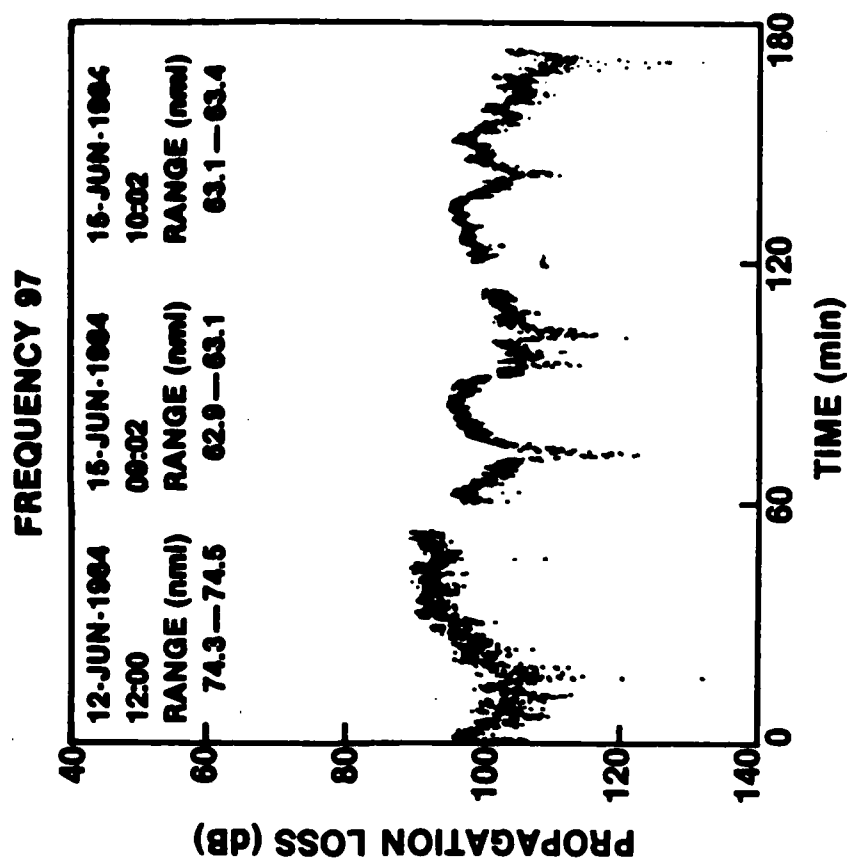


Figure 8

Shown are the locations of the major acoustic participants. A fixed receiver was located at site 0 just off the coast of Svalbard in about 600' of water. The solid lines emanating from 0 are source tow tracks about which more will be said shortly. An experiment on medium stability similar in concept to what has already been described for the Pack Ice was conducted by transmitting long duration CW tones from an acoustic projector slung over the side of the Polar Queen whose general location is shown by the letters P. Q.. This ship was anchored to a flow well into the MIZ. The signals were received on a fixed hydrophone at site 0. It should be noted that the Polar Queen was not absolutely fixed in space over the transmission time since it drifted along with the flow. The maximum average drift rate was measured to be .4kt while at other times no drift rate was measured. This should be compared to the drift rate of the fixed source in '82 Pack Ice data which typically averaged about 1nm per day. No attempt to date has been made to remove the effect of the drift of the ship from the '84 data. Hence, we will be examining the effects of medium instability in the MIZ from a source which is moving extremely slowly.



TRISTEN/MIZEX-84 **FIXED SOURCE/FIXED RECEIVER** **POLAR QUEEN TRANSMISSION LOSS vs. TIME**

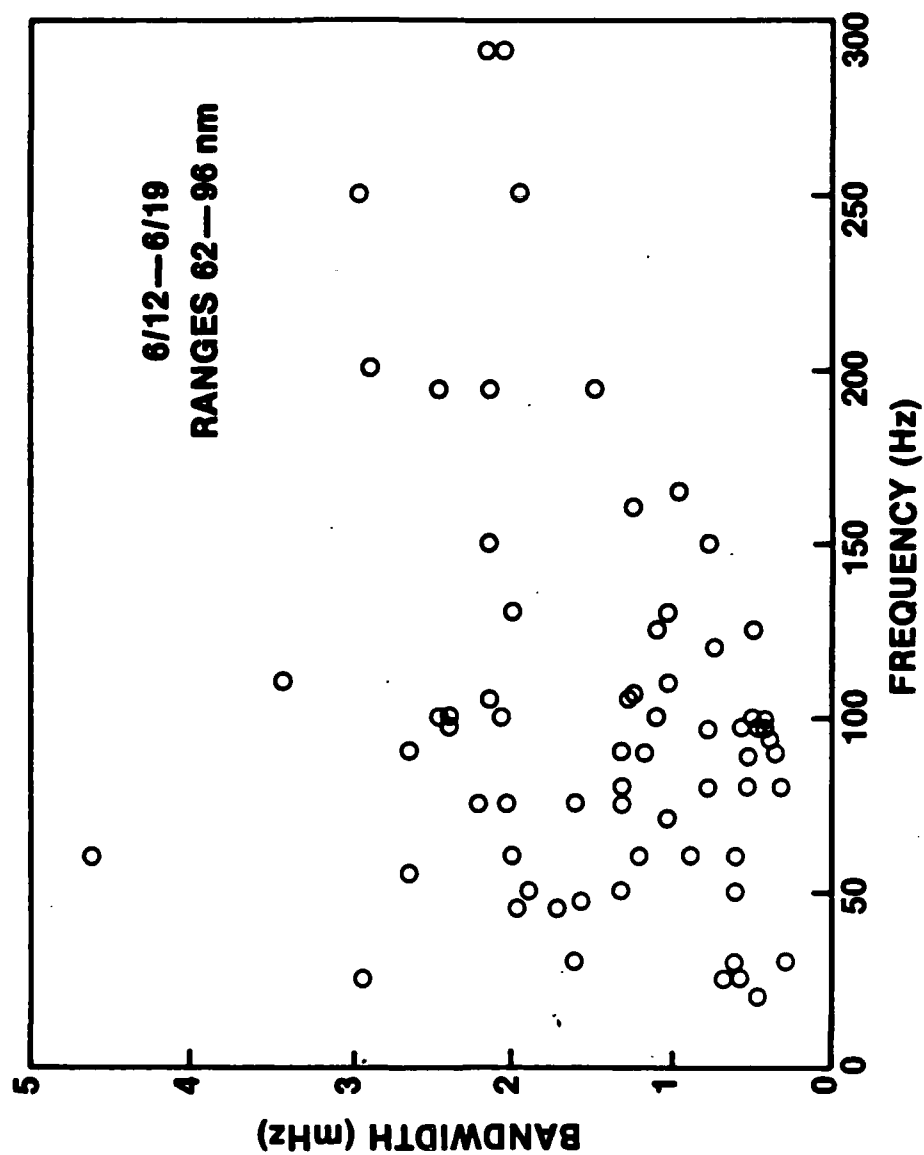


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Figure 9

Shown is the transmission loss versus time at 97Hz for a 1 hr transmissions on June 12 to the extreme left and two consecutive 1 hr transmissions on June 15. The drift rate for the first two transmissions was .2kt, while for the last transmission it was .3kt. Amplitude fades of up to 20db can be observed in the middle record. The received pressure for all such CW transmissions was processed in exactly the same manner as the medium stability transmissions from the '82 Pack Ice data.

TRISTEN/MIZEX-84
NARROW BAND MEDIUM STABILITY
FIXED SOURCE/FIXED RECEIVER



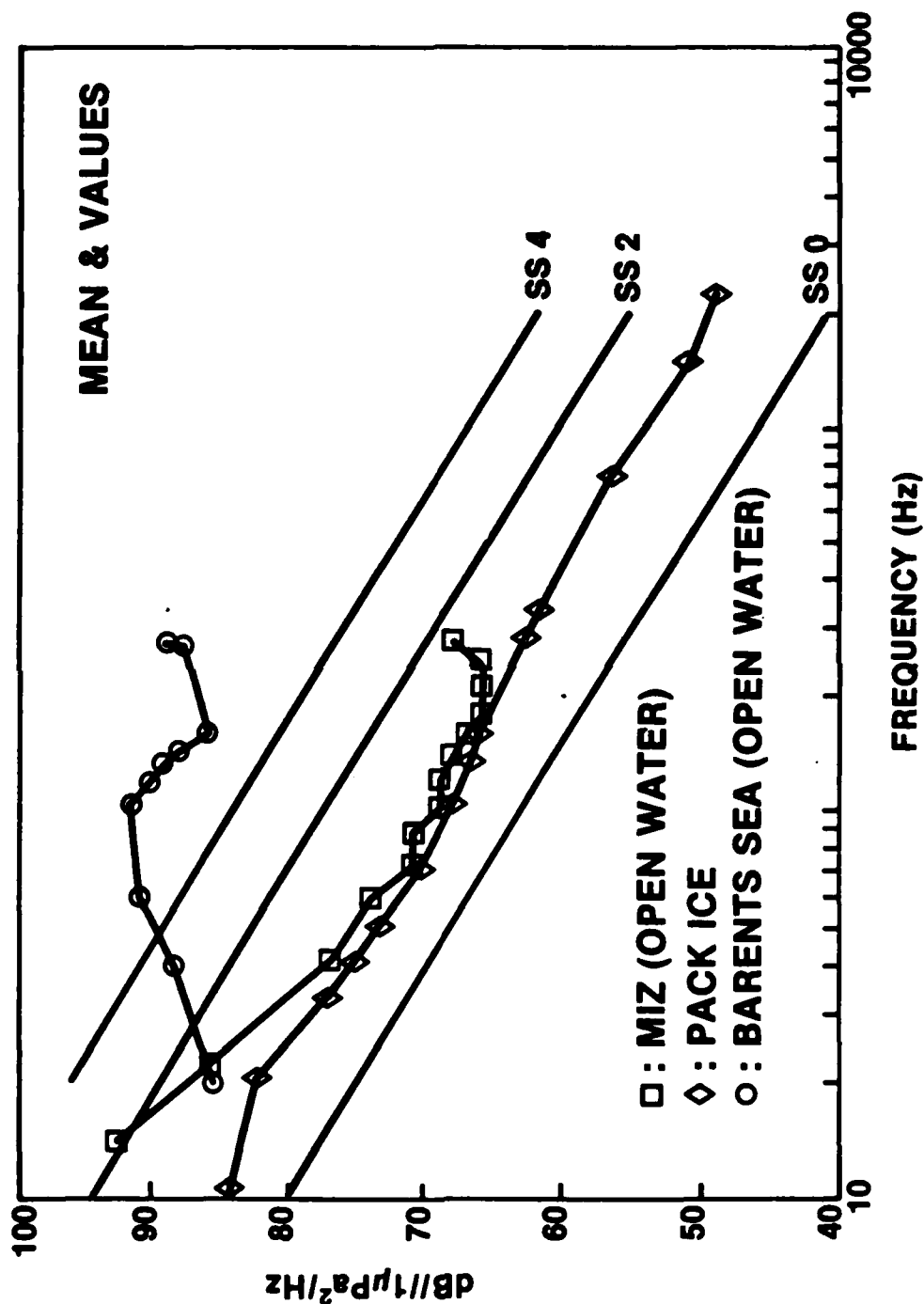
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Figure 10

The bandwidth is plotted in mHz along the vertical axis and the CW transmission frequencies are plotted along the horizontal. Data was taken over approximately a 1 week period during which time the ranges between the source and receiver spanned the interval from 62 to 96 miles due primarily to a relocation of Polar Queen toward the end of the week. If you recall, the bandwidth results for the Pack Ice for frequencies below 100Hz were all less than 1mHz. In the MIZ at frequencies below 100Hz we are seeing values 2 to 3 times as large. Medium stability measurements made by WHOI in more temperate waters near Eleuthera and analyzed by Mikhalevsky to remove source motion effects show bandwidths at 220Hz of 5-8mHz. Our measurements in the neighborhood of this frequency which include the effects of a slowly drifting source show bandwidths of 3mHz maximum. The fact that the MIZ bandwidths are larger than those obtained in the Pack Ice is not to surprising. However, the fact that they are slightly smaller than those from more temperate waters at 220Hz is surprising since the MIZ is usually considered to be one of the most dynamic environments for acoustics.

TRISTEN AMBIENT NOISE SPECTRA



L60829p



Figure 11

We next discuss the topics of propagation loss and ambient noise in the Arctic open water regions. The two upper curves are mean ambient noise results from two different Arctic open water regions. The lowest curve is the Pack Ice result shown earlier and included as a point of reference. The upper most curve was obtained in the ice free Barents Sea well off the coast of Norway in about 1000' of water. Noise in this area at the frequencies shown is dominated by shipping which accounts for the high average level. This curve however, has about a 20db variance associated with it. Thus when local shipping is absent it is possible to find noise levels in the Barents Sea which are as low as the average curve found in the Pack Ice. The middle curve was obtained at site 0 in 1984 off the coast of Svalbard in open water having a depth of about 600'. It is felt that the lower levels associated with this open water region as compared to the Barents Sea can be attributed to the lower level of local shipping in this area. Whereas we felt quite comfortable in our ability to predict the mean level of ambient noise versus season anywhere in the deep water Pack ice, such is not the case in either the MIZ, as mentioned earlier, nor the Arctic open water regions. The noise level in these regions is highly dependent on location in addition to time of year.

TRISTEN 84

861135 NORTH

VESTSPITSGEREN

P.O. K ICE EDGE

D

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H

K

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P

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X

Y

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80°

78°

76°

74°

10°W

5°W

7°0.75'W

74°15'N

10°W

Figure 8

The Arctic open water regions can generally be described mathematically as range dependent propagation environments due to a change in bottom bathymetry and sound speed profile with both range and azimuth. Additionally many of these regions are in shallow water. Thus even without the presence of the ice canopy found in the Pack Ice, characterizing transmission loss in the Arctic open water regions is considerably more difficult than for the deep water Pack Ice. The TRISTEN/MIZEX-84 experiment provided the opportunity to assess just how complicated this process is. The results of transmission loss runs will be discussed for the tracks (see figure 8) OF, which was in shallow water along the coast of Svalbard, OG which traverses the Mid Atlantic ridge and OI and OJ which experience deeper water and a smoother bottom bathymetry at the farthest points from the receiver which was located at point 0 in very shallow water about 600'.

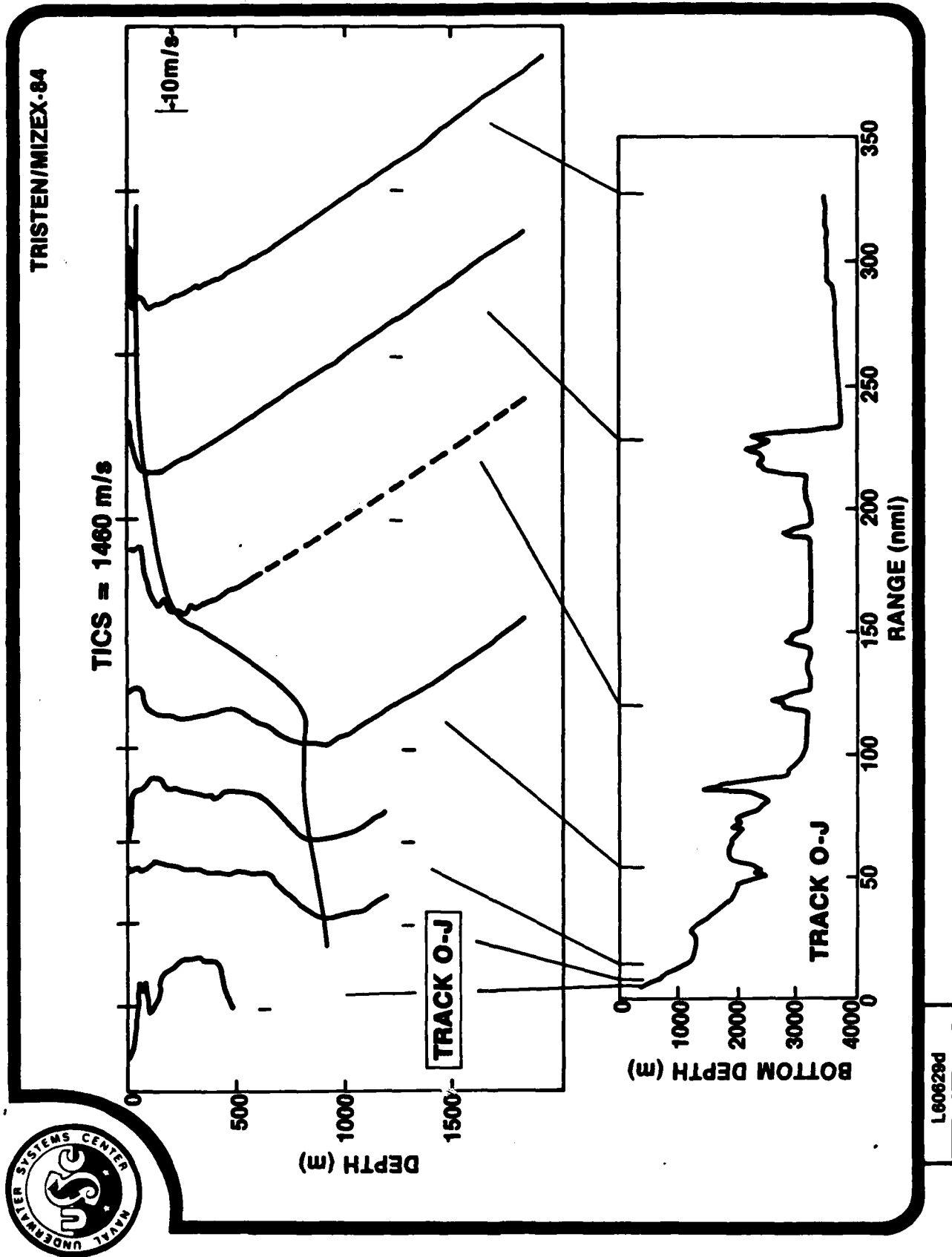


Figure 12

Figure 12

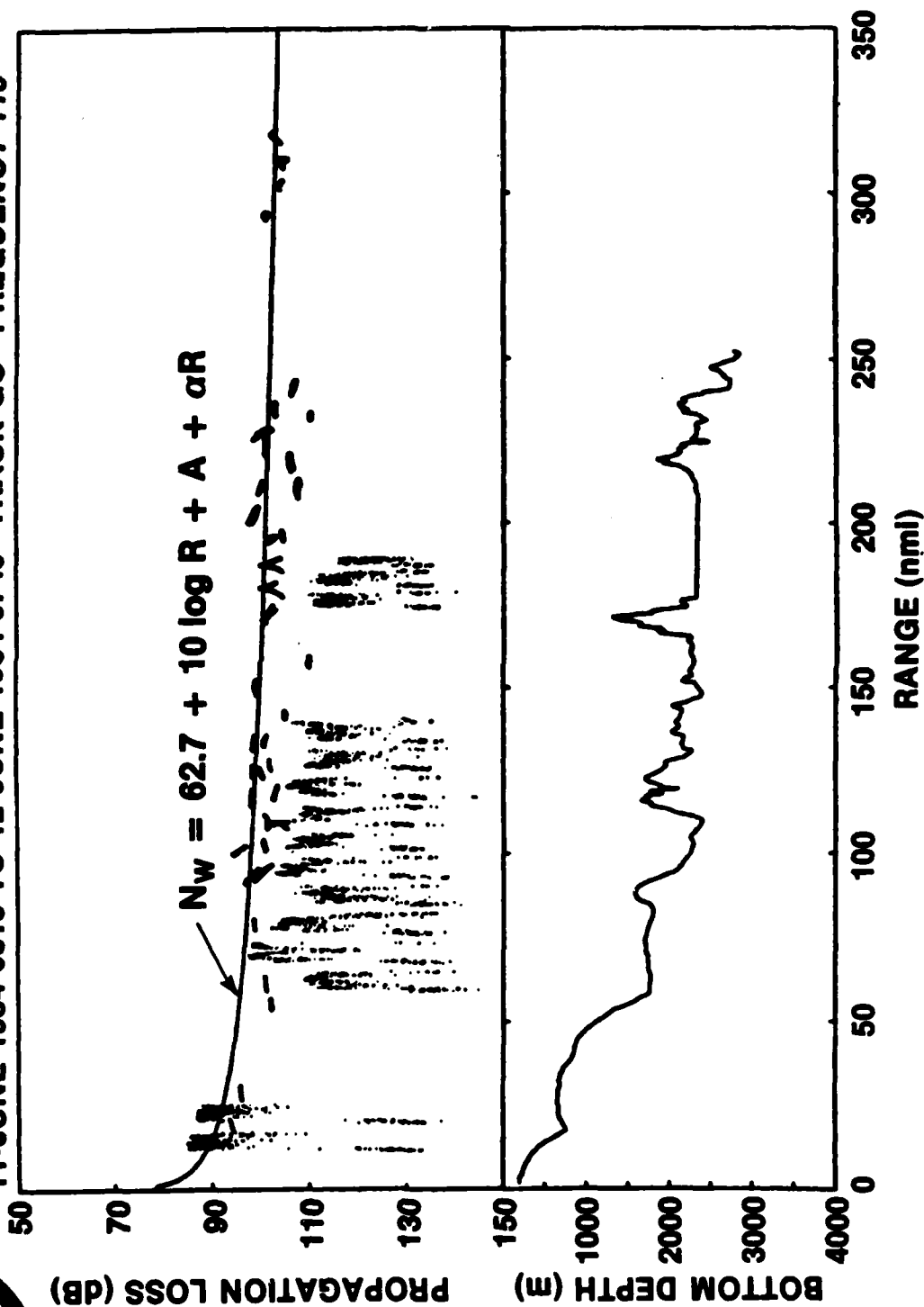
The sound speed was found to have a significant variation in both range and azimuth. An example of the sound speed range dependence along one azimuth is shown in the upper portion of the viewgraph. It can be seen that the character of the profile changes rather abruptly at about 50nm from the receiver. This roughly corresponds to the beginning of the Svalbard Rise along this azimuth as can be seen from corresponding bottom bathymetry shown in the lower portion of the viewgraph. The steepness of the bottom slope in front of the receiver out to about 50nm also changes significantly with azimuth. Track GO which had the smallest bottom slope in this region experienced the largest loss.



TRISTEN/MIZEX-84 (OPEN WATER)

PROPAGATION LOSS VS. AZIMUTH

11-JUNE 1984 0816 TO 12-JUNE 1984 0740 TRACK GO FREQUENCY 110



L60629k

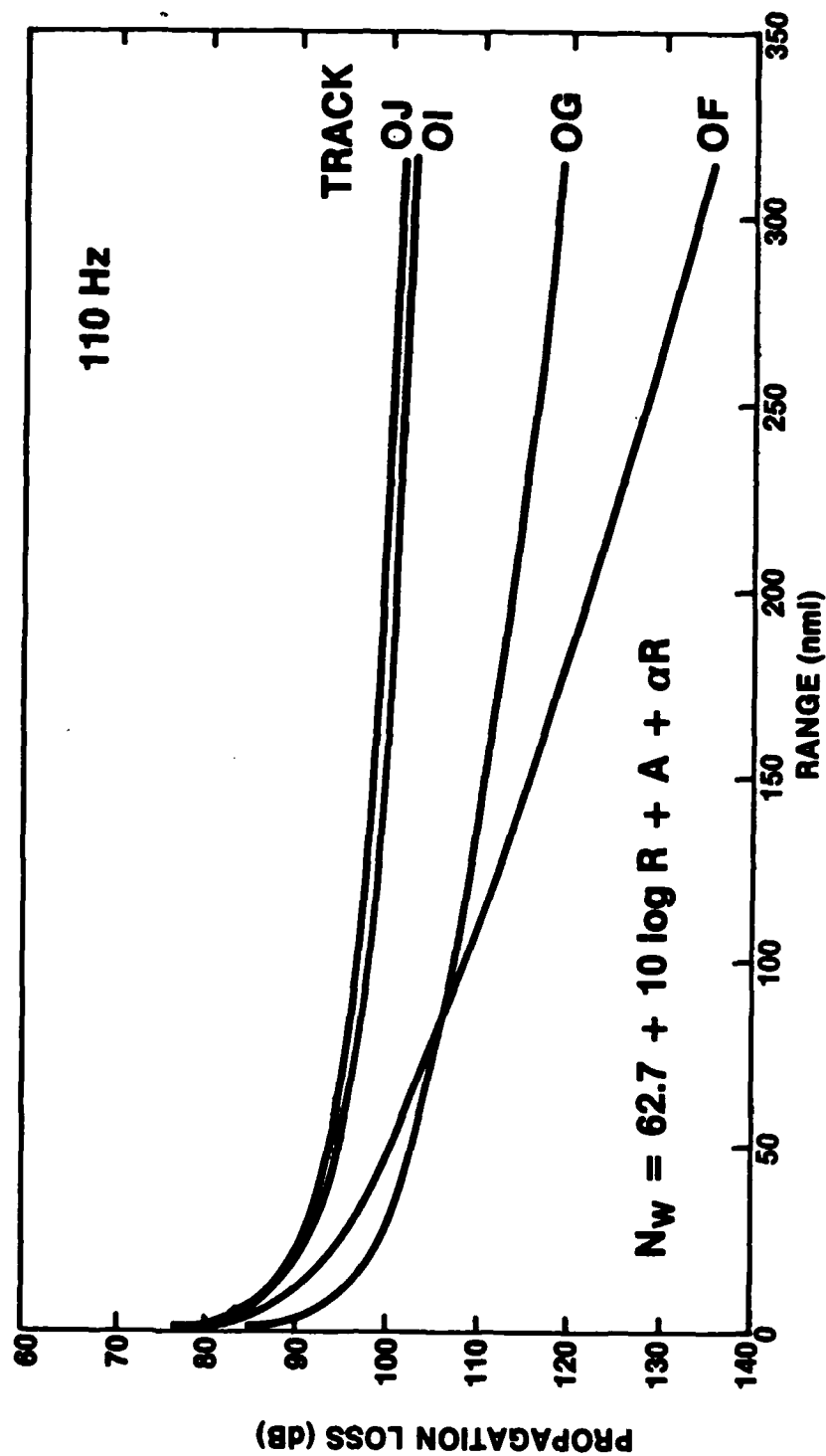
Figure 13

Figure 13

The transmission loss data at 110Hz for track GO, which had the smallest bottom slope in front of the receiver is shown by the dots. We have also overplotted the peak values of transmission loss at 110Hz for tracks JO and OI both of which had considerably larger bottom slopes in front of the receiver. We believe that the smaller bottom slope in front of the receiver for track GO is the cause of the increase in transmission loss. In an attempt to quantify this extra slope loss, the data from tracks GO, JO and OI was fit at the longer ranges for all frequencies with the expression $62.7 + 10 \log(R) + \alpha R$. The fit shown is for track JO. The term α was zero for all tracks except OF, which was in very shallow water along the coast of Svalbard and track GO at only 110Hz.



TRISTEN/MIZEX-84 **PROPAGATION LOSS vs. AZIMUTH**



L60629b

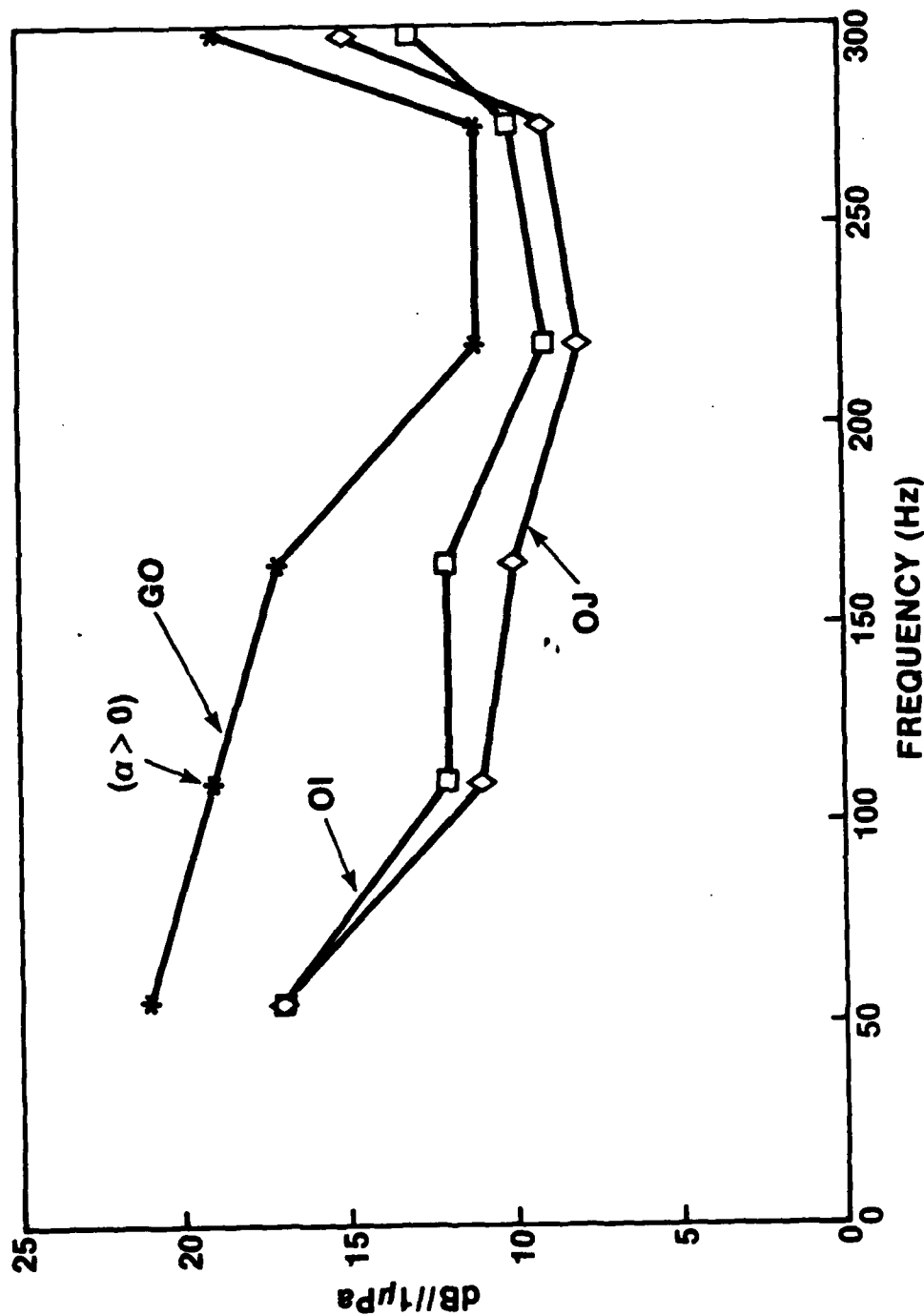
Figure 14

Figure 14

The long range fits to the data for all tracks are shown for a frequency of 110Hz. The OF track ran along the coast of Svalbard and consequently experienced considerable more shallow water than the other tracks which accounts for larger loss. In an attempt to quantify the effect of the azimuthal dependence of bottom slope in front of the receiver we next plot the value of the constant A versus frequency for the three tracks GO, JO, and OI which have deeper water at long ranges.



TRISTEN/MIZEX-84 (OPEN WATER) "SLOPE LOSS" CONSTANT (A) vs. FREQUENCY



L60629q

Figure 15

Figure 15

Increasing values for the constant A are plotted in the upwards direction along the vertical axis, while frequency is plotted along horizontal. The larger the value of A, the greater the loss. Thus the fact that the curve for GO lies above all the other curves for all frequencies is believed to be a measure of the increased loss caused by the smaller bottom slope in front of the receiver along that azimuth.

The curves for JO and OI are closely related which also correlates with the fact that the bottom slopes in front of the receiver along these azimuths are similar.

All curves also have a minimum value in the vicinity of 220Hz indicating that the best transmission loss occurs at this frequency for all three tracks with greater loss occurring at both higher and lower frequencies. This behavior is typical of propagation in shallow water which reinforces the notion that it is the shallow bottoms depths within the first 50nm miles in front of the receiver that dominate the propagation picture.



SUMMARY

TRISTEN EXPERIMENTS CONDUCTED IN 80, 82 & 84

ACOUSTICS	PACK ICE	OPEN WATER	MIZ
ENVIRONMENTAL/ MATHEMATICAL DESCRIPTION	<ul style="list-style-type: none"> • DEEP WATER, RANGE INDEPENDENT (LF) 	<ul style="list-style-type: none"> • MOSTLY SHALLOW, RANGE DEPENDENT (LF) 	<ul style="list-style-type: none"> • MOSTLY SHALLOW, RANGE DEPENDENT (LF)
STABILITY	<ul style="list-style-type: none"> • EXTREMELY STABLE 	?	<ul style="list-style-type: none"> • ? (BUT LESS STABLE THAN PACK ICE)
N _w	<ul style="list-style-type: none"> • MEAN LEVELS PREDICTABLE FROM EMPIRICAL MODELS • ICE SCATTERING LOSS MAJOR UNRESOLVED ISSUE AT LF 	<ul style="list-style-type: none"> • LOCATION/SEASON DEPENDENT • PREDICTABILITY (?) 	<ul style="list-style-type: none"> • HIGHLY LOCATION/SEASONAL DEPENDENT • PREDICTABILITY (?)
	<ul style="list-style-type: none"> • MEAN LEVELS PREDICTABLE FROM EMPIRICAL MODELS AT LF 	<ul style="list-style-type: none"> • LOCATION/SEASON DEPENDENT • PREDICTABILITY (?) 	<ul style="list-style-type: none"> • HIGHLY LOCATION/SEASON DEPENDENT • PREDICTABILITY (?)
AMBIENT NOISE			

L60626v

Figure 16

Here we attempt to loosely summarize the results of the TRISTEN low frequency experiments in the areas of medium stability, propagation loss and ambient noise for the three distinct Arctic Environments.

We found that the Pack Ice can be described mathematically as being a range independent deep water environment. It has a high medium stability, perhaps the highest of any underwater acoustical environment. Mean levels for propagation loss are predictable from empirical models, although our understanding of scattering loss is unresolved. The mean ambient noise levels are predictable and found to be generally lower than those from more temperate oceans.

The MIZ and open water regions lie predominantly over shallow water and are found to be highly range dependent. TRISTEN stability measurements were not made in the open water but those made in MIZ although found to be higher than the Pack Ice were not higher than a temperate ocean measurement at 220Hz, which was a little surprising. However, it may well be that additional measurements are required in different locations and seasons before a definitive conclusion can be reached regarding MIZ medium stability. Propagation loss and ambient noise in both regions is highly variable, certainly dependent on location and most likely on seasons as well.

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A REVIEW OF TRISTEN
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